

Application of Oligomers with Urea Linkage as Flame Retardant and Antibacterial Materials in Jute Fabric

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Abstract- In this study, the application of mixed oligomers containing urea linkage as flame retardant and antibacterial agent in jute fabric was investigated. The mixed oligomers were produced using various molar ratios of urea and other inorganic acids such as sulfamic and phosphorous acid at a specific temperature. The reactions occurred in melt state in the temperature range of 130-150 °C. An aqueous solution of 50% of products was applied to the jute fabric with 80% wet pick up, then dried at 80 °C and cured at 170 °C for 2 min. The chemical structures of the new materials were studied using FTIR. The SEM micrograph of the surface of the specimens was presented along with the elemental analysis information using EDAX technique. The thermal decomposition analysis results by applying DSC and TGA techniques were also reported. The limited oxygen index of treated samples showed high level of fire resistant improvement with desirable wash durability. Antibacterial properties of treated samples were indicated against *Staphylococcus aureus* and *Escherichia coli* bacteria. In conclusion, it was found that the amount of phosphorus plays a significant role in antibacterial and flame retardant performance of jute fabric. The high level of limited oxygen index (0.41%) was measured for sample treated with the compounds prepared from 2 moles sulfamic acid, 3 moles phosphorous acid, and 8 moles of urea.

Keywords: flame retardant, jute fabric, oligomer, finishing

I. INTRODUCTION

The application of natural fiber as reinforcing material in composite materials has been improved recently. Biocomposite is being targeted in various fields due to the environmental and economic benefits [1]. Jute fiber with specific characteristics such as biodegradability, abundance, renewability, low cost, high tensile strength, and low specific gravity is one of the best selection in bast fibers [2]. However, the high content of -OH polar group

of this fiber reduces its compatibility with hydrophobic polymer matrices. The aggregation during processing and poor resistance to moisture absorption affect some mechanical properties of its composite [3]. The hybrid composites made of 50% by weight of jute fabric sandwiched in 4 layers between 5 layers of polypropylene, polyvinyl chloride, and a mixture of these two polymers were prepared using injection molding and heat pressing. Finer particle size aluminum trihydrate and zinc borate with antimony trioxide were used as fire retardants. The improvement of fire retardancy of the composite without any loss of mechanical characteristics can be achieved by using chemically reactive fire retardants at low concentrations. Hybrid composite of 55% PP and 45% PVC showed the best results and was selected as desired specimen [4]. The mixture of polypropylene and ammonium polyphosphate (APP) powder was spread over the surface of jute/PP nonwoven felts, and then transformed into the flame retardant layer by the hot pressing process. The flame retardancy and thermal properties of composites were investigated [5].

The application of flame retardant (FR) on jute fiber and fabric was also investigated in several researches. Recently the study of acoustic and flammability properties of jute fiber and its composite for noise reduction in household applications, automotive, and also architectural applications has been reported. The composite was prepared using natural rubber latex as a matrix [6]. In another research, the flame retardant materials were applied to jute/polypropylene fiber needle felt at various flame retardant concentrations and also dipping times. The results were indicated with LOI (35.2%) and some other acceptable properties [7]. The flame retardancy treatment was imparted to the jute fabric using organophosphorus flame retardant (OFR) and tetrakis(hydroxymethylk) phosphonium chloride (THPC). There was an increase of up to 116 and 46% in LOI value compare to the untreated fabric. In TGA analysis result, for the FR fabric, and a large amount of char residue was left [8].

Nano zinc oxide in aqueous solution of potassium

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methyl siliconate was applied to the bleached jute fabric by pad-dry method. The application of a 0.01% of nano ZnO on the jute fabric showed reasonably good fire retardant performance. The value of LOI was well confirmed for as many as five wash cycles [9]. The treatment of jute fabric was carried out by impregnation of sodium stannate (20%) followed treatment with boric acid (20%) in a double-bath process. The balanced flame retardancy property (LOI value 34) with some loss in fabric tenacity (about 14.5%) has been reported [10].

The thermal behavior of flame retardant jute fabrics impregnated with a diammonium hydrogen phosphate (DAP) and urea (1:2) solution was studied. The thermal behavior of jute fabric and its main components, α -cellulose, holocellulose, hemicellulose, and lignin, was also determined [11]. The bleached jute fabric has been dyed with selective acid dyes (1%) and chemically finished with different concentrations of ortho-phosphoric acid, ammonium sulfamate, and di-ammonium phosphate for fire retardant finish in a single-step simultaneous process by pad-dry-cure technique. The effective treatment has been confirmed [12]. Antibacterial functionalities and flame retardant properties were achieved on jute fabric using sodium metasilicate nonahydrate (SMSN), known as a "water glass". The treatment has been occurred by pad-dry technique. The application of 2 w/v% solution of SMSN to the fabric decreased the rate of fabric burning by almost 10 times compared to the control sample [13].

Oligomer with a special molecular structure and limited molecular mass constituted of a set of similar or different units that were repeatedly connected with each other. The functional groups appeared on its structure play a significant role on its physical and chemical properties. The design of functional groups on its structure is also possible. These products can be applied over the most different tasks for example be good wetting and adhesion relative to surface, cross-linking reactions in plastic or adhesive formulations but also specific fixing and release of active substances.

The mixed oligomers in this research were produced with different structure and properties depending on the type and molar ratio of the initial materials, the time and the reaction temperature. These compounds are referred to as urea-condensate compounds [14], but their structure and properties are known as cross-linkers, therefore, it is better to call them urea-linkage oligomers due to the urea bonds formed in the main chains. At lower temperature of 160 °C, the linear structure and over 170 °C, the cyclic oligomers were identified. The urea and urethane linkage have been appeared on the main chain with NH₂ and OH end group terminations therefore their activity

TABLE I
FABRIC CHARACTERISTICS

Characteristics	Value
Area density g/m ²	1020
Denier density (warp and weft)	1350 Tex (Nm=0.74)
Warp density (ends/inch)	10
Weft density (picks/inch)	8

for further reaction is clear. The oligomers molecule with phosphorus, sulfur, and nitrogen on their structure can facilitate the specific position of this material as a flame retardant to cellulosic fibers.

The new initiative used in this research is the use of a new oligomer composition with different molar ratio of the raw materials, 2 moles of sulfamic acid, 3 moles of phosphorus, and 8 moles of urea. This compound, unlike other weight ratios, is in the gel form (other urea condensate products are crystalline). The antibacterial properties of the samples are also studied in this report. Information on this behavior and confirmation of antibacterial properties with this supplement is also provided for the first time. In fact, the amount of phosphorus and sulfur on the surface of the fabric was associated with the observed antibacterial activity.

II. EXPERIMENTAL

A. Materials

The raw plain weave jute fabric was prepared from market. The characterization of fabric is indicated in Table I. The fabric was pre-treated in 3 g/L of Na₂CO₃ and 1 g/L of non-ionic detergent, L: R 20:1, at 80 °C for 30 min.

The initial chemical materials, sulfamic acid, phosphorous acid and urea were all supplied by Sigma-Aldrich, UK.

B. Fourier-Transform Infrared Spectroscopy (FTIR)

The chemical structure of new products and also treated fabric samples was studied using Perkin-Elmer 1740 FTIR spectrophotometer with diamond ATR attachment.

C. Elemental Analysis

The elemental analysis was carried out on a Carlo-Erba 1106 Elemental analyzer to detect the C, H, N, S, and P on treated sample.

D. Energy Dispersive X-ray Spectrometry

The chemical stoichiometry of prepared fabric samples before and after washing was studied using secondary electronenergydispersiveX-rayspectrometry(SEM/EDS). The instrumentation utilized was a Jeol JSM-6610LV scanning electron microscope, in conjunction with an

Oxford Instruments INCA X-max80EDS system.

E. Flammability Test

The procedure was carried out according to the vertical strip test as BS EN ISO 6941/2 tests, in which a vertically oriented fabric sample is subjected to a standard igniting flame source on the surface of fabric for 10 s.

F. Color Difference Study

The color difference of fabric sample before and after treatment was studied using a Color-Eye 7000 A Gretag-Macbeth spectrophotometer.

G. Thermal Analysis

Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) were performed using a DSC 2010 (TA instrument Ltd) under nitrogen atmosphere from room temperature. Typically, 5 mg to 10 mg of sample was heated at a rate of 10 °C/min with a purge gas flow of 200 cm³/min. Data were recorded using thermal advantage software.

H. Limited Oxygen Index (LOI)

The flame resistant performance of samples was studied using a Candle Type Flammability Tester, No.606 model D from the TOYOSEIKI Company made in Japan, according to ASTM D2863 Standard Test in Central Iran Research Complex in Yazd city, Iran.

I. Antibacterial Activity Properties

The antibacterial activities of the treated samples were tested against *Escherichia coli* (Gram negative) and *Staphylococcus aureus* (Gram positive) cultures according to the AATCC Test 100-2012 standard methods. These tests were carried out in Absar Kavir, Industrial Research Company in Yazd, Iran.

J. Preparation of New Materials

The water soluble oligomers were synthesized using urea, phosphorous acid and also sulfamic acid in various molar ratios, in melt conditions at maximum 150 °C while the evolved gas removed by condenser.

2S/3P/8U: 2 moles sulfamic acid, 3 moles phosphorous acid, and 8 moles of urea.

1S/1P/10U: 1 mole of sulfamic acid, 1 mole of phosphorous acid, and 10 moles of urea.

1S/4U: 1 mole sulfamic acid and 4 moles of urea.

1P/4U: 1 mole phosphorous acid and 4 moles of urea.

The weight ratios were selected after various experiments, aiming to produce a high quality product, low cost and convenient reaction control. It should be noted that

these products are produced during a short time thermal condensation reaction.

The product from the ratio of 1 to 4 sulfamic acid to urea was a stable gel that was easily collected while other weight ratios resulted in a hard solid product. In the case of 1:4 phosphorous acid:urea (1P/4U), the reaction occurred with high controllability, in fact in a very short time the condensation reaction developed very rapidly and after a few minutes a large amount of gas evolved from the vessel, and after while the reaction took place with gas removal very slowly. It was concluded that the product could be produced more uniformly with proper control.

According to these descriptions the combination of these two substances should be 1 mole of sulfamic acid, 1 mole of phosphorous and 8 moles of urea. Due to the application of the products, a new combination of higher phosphorus and sulfur content with higher efficacy was considered as a flame retardant. The 2S/3P/8U compound is also produced as a fully stable gel, which demonstrates ease of collecting with high level of controllability of the reaction.

In the design of the experiment, with these various synthetic products, the initial coating materials were selected as the only variable through the work. The conditions of finishing treatment were considered constant for all samples. In fact, various treated fabrics containing different amounts of sulfur, phosphorus and nitrogen on their structure are produced.

The effect of each element on the burning behavior and antibacterial properties of the fabrics will be studied.

K. Fabric Treatment Procedure

The finishing process was carried out using 50% aqueous solution of synthesis materials, 10 g/L of non-anionic wetting agent, with 80% wet pick up. The jute fabrics were dried and cured at 80 and 170 °C for 2 min.

L. Treatment Durability

The treated samples were washed with hard water according to this procedure: L: R, 20: 1, 2 g/L of sodium carbonate and 2 g/L non-ionic wetting agent at boiling temperature for 15 min.

III. RESULTS AND DISCUSSION

A. FTIR Spectroscopic Analysis

The predicted chemical structure of the products was studied using FTIR, NMR, and also mass spectroscopy spectra [14]. In this research, we focus only on the spectrum information of the new synthetic sample prepared from 2 moles of sulfamic acid, 3 moles of phosphorous acid,

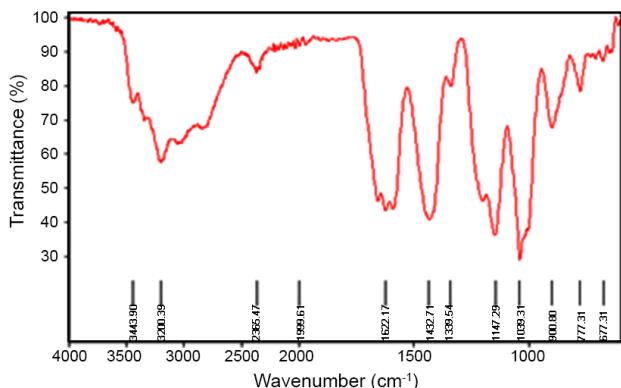


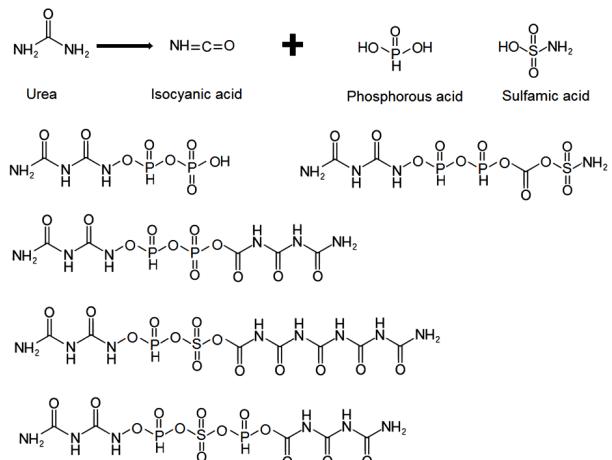
Fig. 1. FTIR spectrum of 2S/3P/8U compound.

and 8 moles of urea (2S/3P/8U) as shown in Fig. 1.

Two strong bands representing NH_2 and NH stretching vibration for the primary amides appeared at 3500–3000 cm^{-1} . The moderate intensities seen in this frequency range represent the same functional groups. The decrease in peak intensities of these amide functional groups is due to the presence of the hydroxyl group in this product. In fact, the high level of phosphorous and also sulfamic acid as an initial material in synthesis of this compound led to the new products with some hydroxyl groups at the end of urea-linkage oligomer chain. In the FTIR spectrum a very wide band at wavenumber of 3200.39 cm^{-1} may be attributed to the OH stretching vibration of the hydroxyl groups in the products. These provided hydroxyl groups facilitate the reaction between cellulose and new compounds.

In this FTIR spectrum, the intensity values of specific band at 1039.31 cm^{-1} may be relevant to the alkyl sulfonic acid, RSO_2OH , and also the PO_3^{2-} functional groups. According to the reference [15], the P-O-H stretching vibration of phosphorous acid has a medium weak intensity peak at the region 1040–910 cm^{-1} . The P-N stretching vibration is also indicated at 2900–2760 cm^{-1} . However, in this spectrum, the overlapping of some specific bands made it unclear. In phosphorous compound, the P=O stretching vibration occurs in the wavenumber range from 1234 cm^{-1} to 1404 cm^{-1} . Many of the phosphate esters exhibit a doublet band due to the existence of rotational conformers, and the wavenumber separation for these two bands varies between 7 and 29 cm^{-1} [16]. The specific band situated at 1432.71 cm^{-1} can be attributed to these new functional groups appeared in the products due to high level of phosphorous acid applied in the reaction.

As mentioned before, information about mass spectrum and NMR is provided in the source [14], which is not required to be repeated here. From the NMR results



Scheme 1. Possible chemical reaction occurred between urea, phosphorous acid, and sulfamic acid.

the urea linkage is the main functional group identified in products. Therefore the formation of urea oligomer with various monomers can be claimed as the main products at this temperature. The products suggested in Scheme 1 are completely in agreement with the molecular weight obtained from the mass spectrum results.

In fact, at temperatures above the melting point of urea, isocyanic acid is produced as an active ingredient capable of reacting with urea, sulfamic acid, and phosphorous acid functional groups [14]. With the condensation reactions and the withdrawal of water and ammonia molecules in the form of gas, new chemical bonds are formed, a series of which is indicated here. Two or three or more interconnected urea molecules can be considered that are identified at the end or the middle of the oligomeric chain by phosphorus or sulfur functional groups.

B. FTIR Results for Treated Fabric

The FTIR spectra of two fabrics, the main untreated fabric, and the one treated with 2S/3P/8U compound are shown in Fig. 2. The intensity of some bands in 3500–3000 and 1000–1700 cm^{-1} region represents the new functional

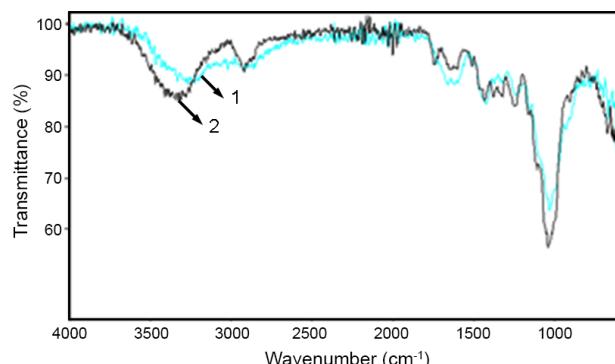
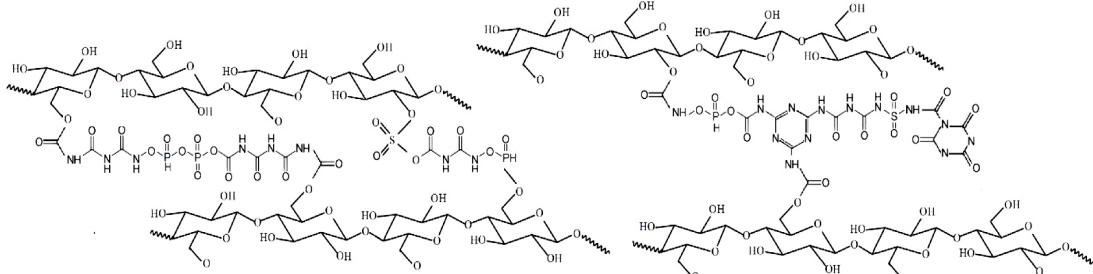


Fig. 2. FTIR spectra of: (1) untreated jute fabric and (2) treated fabric.



Scheme 2. Possible chemical reaction occurred between the synthesized products and jute treated sample.

TABLE II
ELEMENTAL ANALYSIS OF UNTREATED JUTE FABRIC AND SAMPLES TREATED WITH VARIOUS TYPES OF UREA PRODUCTS

Analyzed elements	Untreated fabric	Treated samples				Washed sample (Treated with 2S/3P/8U)	
		1S/4U	1P/4U	1S/1P/10U	2S/3P/8U	5 cycle	10 cycle
Carbon	47.0	43.2	43.3	40.5	45.1	44.8	44.6
Hydrogen	7.66	7.16	7.40	7.20	7.38	7.65	7.38
Nitrogen	T/N*	6.93	7.30	1.30	1.08	T/N	T/N
Sulfur	T/N	0.62	-	0.55	1.12	0.88	0.53
Phosphorus	T/N	-	1.63	1.75	4.22	3.30	1.56

groups produced on the treated fabric such as NH_2 and NH functional groups and new carboxyl groups. The specific bands in the new samples are due to sulfur and phosphorus groups in the wavenumber region $1000\text{-}1300\text{ cm}^{-1}$. The possible chemical reaction occurred between the new compound and jute treated sample is shown in Scheme 2. In fact, during curing process at high temperature ($170\text{ }^\circ\text{C}$), the water-soluble aliphatic polymer chains with different lengths and urea linkage can transfer to the water-insoluble aryl-aryl and alkyl-aryl urea with urethane linkage [14].

C. Elemental Analysis of Fabric Treated with Synthesized Materials

The elemental analysis of untreated jute fabric and the fabric treated with various types of oligomers is compared in Table II. A sufficient but still very small phosphorus and sulfur elements is evident on the treated fabric which is able to produce a flame retardant fabric.

The liberation of ammonia as the main gas during curing process may be caused to reduce the level of nitrogen on the fabric.

The durability of the treated samples to laundering process was studied using the elemental analysis for samples treated with 2S/3P/8U product. The samples were washed for 5 and 10 cycles in a washing machine with a Persil Color Care washing liquid. The information is indicated in Table II. The desirable amount of sulfur

and phosphorus elements on the fabric after laundering process can confirm the wash durability of the treatment.

D. SEM and EDAX

The SEM images of the surface of untreated sample and treated with urea linkage oligomers are shown in Figs. 3 and 4. On the surface of the unfinished fabric, solid

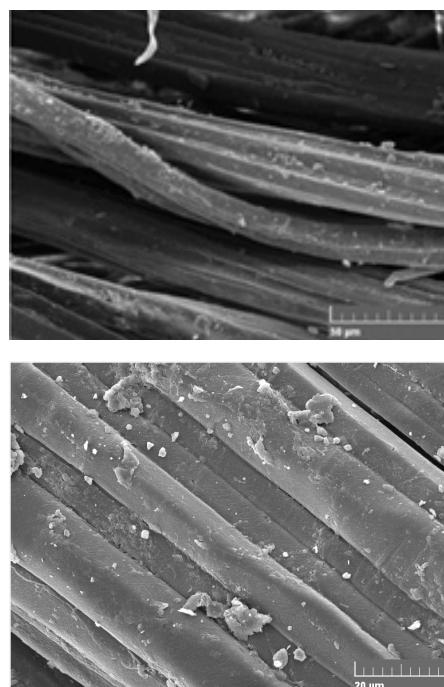


Fig. 3. SEM images of non-treated sample at two different magnifications.

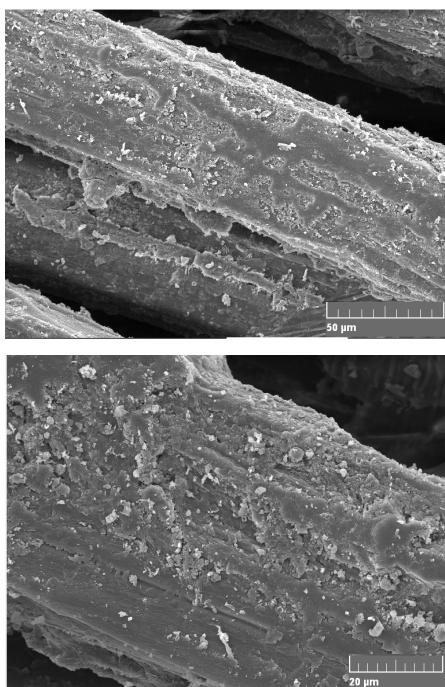
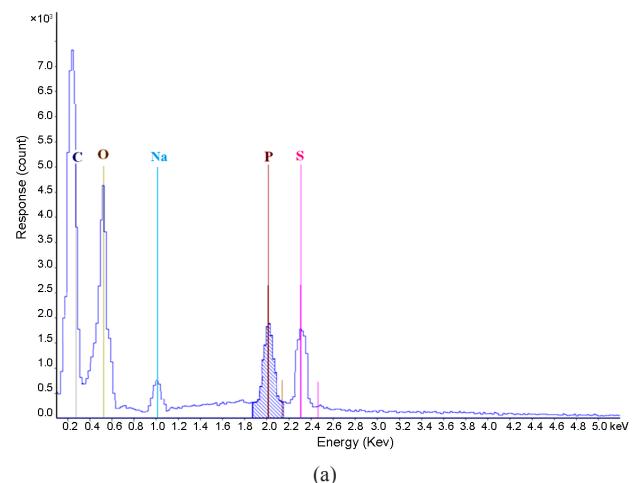


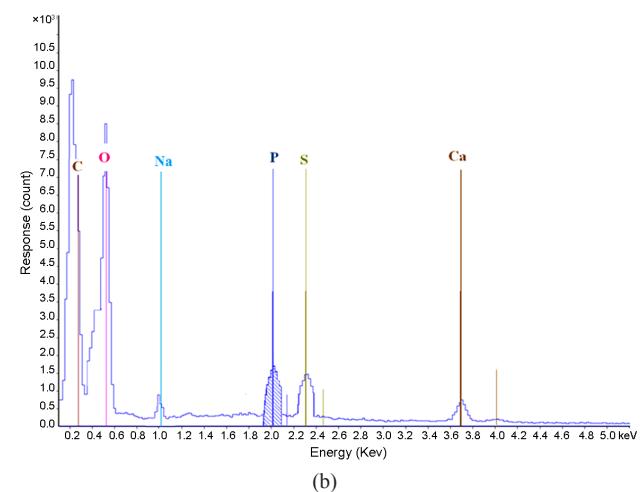
Fig. 4. SEM images of sample treated with 2S/3P/8U compound at two different magnifications.

particles can be seen which can be related to the residual compounds left after the initial washing of the fabric with sodium carbonate. The sodium elements were also detected on the surface of the fabric. As can be seen, after the coating operation, the finishing material is uniformly covered the whole surface of the fiber. Interestingly, despite what the image shows below, the fabric handle was developed to the smoothness surface. The finishing treatment gives a greasy coating on the surface of jute fabric that makes the handle softer than expected.

The analysis performed with the Energy-dispersive X-ray (EDAX) technique provided more complete information about the distribution of elements on the surface of the samples shown in Fig. 5. The elemental data collection is recorded in Table III. The amount of phosphorus and sulfur is favourably observed on the two finished fabrics before and after washing, indicating acceptable washing stability for the samples. However, it



(a)



(b)

Fig. 5. Elemental analysis using EDAX technique on the surface of the jute fabric treated with the 2S/3P/8U compound: (a) before washing and (b) after washing.

may be possible to modify this process again by changing the process conditions. The presence of sodium and calcium after washing was not unexpected.

E. Flammability Test

The effect of these materials on flammability performance was also studied, and no burning, no glow but small char were observed. The jute sample treated with 2S/3P/8U

TABLE III
ELEMENTAL ANALYSIS OBTAINED USING EDAX ANALYSIS TECHNIQUE ON THE SURFACE OF THE JUTE FABRIC TREATED WITH THE 2S/3P/8U COMPOUND

	Element	P	S	C	O	Ca	Na
Not washed	Atomic (%)	3.84	3.22	32.32	59.47	-	1.20
	Weight (%)	4.02	3.41	32.55	58.01	-	2.01
Washed	Atomic (%)	2.43	1.66	31.22	62.3	1.08	1.31
	Weight (%)	2.60	2.02	34.03	58.36	1.42	1.57



Fig. 6. Vertical burning test on: (a) unwashed flame retardant fabric and (b) washed flame retardant fabric.

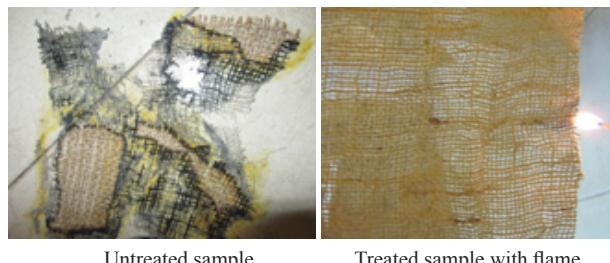


Fig. 7. Burned fabric and flame retardant-containing sample with the flame close to it.

compound was selected for vertical strip test before and after washing. In Fig. 6, the image of the specimens and the amount of char formed at the edge of the fabric can be seen. The durability of this treatment is confirmed in hard water with washing agent. The present of urea, phosphorous and also sulfamic acid changed the procedure of fabric burning to the condensate phase mechanism and more char was expected. The images of burned fabric and also fabric treated with flame retardant close to the flame are shown in Fig. 7.

F. Color Difference

The color of treated jute fabric was changed. The colorimetric parameters of the fabric before and after finishing were studied. The L^* , a^* , and b^* values were obtained using the CIE lab scale with white ceramic tiles as a standard reference. The three coordinates of L^* , a^* , and b^* are listed in Table IV. As can be seen after treatment, at least 5° of difference for the parameter of ΔE is calculated. The treatment of fabric with oligomeric compounds at curing operation has been associated with a series of

chemical reactions that affect the color of the fabric. This color change was not washed away from the fabric. Since the use of these fabrics is mostly defined in the industry, especially in the manufacture of composites, it can be argued that their color change has no effect on the performance of this fabric and this behavior can be ignored. The color of the finished fabrics according to the obtained color parameters changes to reddish.

G. Thermal Analysis Results

The thermal analysis of untreated and treated samples is compared in Figs. 8 and 9. The DSC results of the natural jute fabric demonstrated that the pyrolysis of sample was performed in two steps, below 100°C , as well as removing H_2O molecules through condensation reaction was confirmed. The main decomposition occurred at high temperatures centred at 360°C with formation of levoglucosan and char as the final products. The char residue after pyrolysis assessed using TGA thermogram was about 20% of initial weight of the fabric. In the sample treated with polyurea products, 1S/1P/10U, the first hydrolysis reaction is the same as that of untreated fabric with water evaporation. After that, the pyrolysis was followed with a small exothermic reaction centred at 280°C , representing the production of phosphoric and sulfuric acid to enhance the char formation [17]. In thermal gravimetric analysis (TGA), the treated sample starts to dehydrate at lower temperature, and some volatile materials are removed during heating with high amount of char formation, representing the FR effect on the sample. The flame retardancy performance of samples was confirmed through these two calorimetric results. The procedure of samples pyrolysis is indicated in detail in Table V.

The treated samples were decomposed in three steps, the first pyrolysis process was the same as that of original jute fabric, but the other steps were different. The sample treated with 1S/4U compound shows the exothermic reaction with low level of heat release in the step three. The decomposition process for this sample occurred around the same temperature of untreated jute fabric. The performance of this sample in burning test was self-extinguishing behavior and no proper flame retardancy was achieved.

TABLE IV
COLORIMETRIC PARAMETERS OF THE UNTREATED FABRIC SAMPLE AND ONE TREATED WITH UREA-LINKAGE
OLIGOMER 2S/3P/8U

	L^*	a^*	b^*	c^*	h
Standard	95.75	-0.2	1.21	1.23	99.58
	ΔL^*	Δa^*	Δb^*	Δc^*	Δh^*
Untreated sample	-38.18	7.0 R	18.82 Y	19.92	-2.49 R
Treated sample	-38.58	9.92 R	21.80Y	23.75	-3.10R
					ΔE
					30.98
					36.01

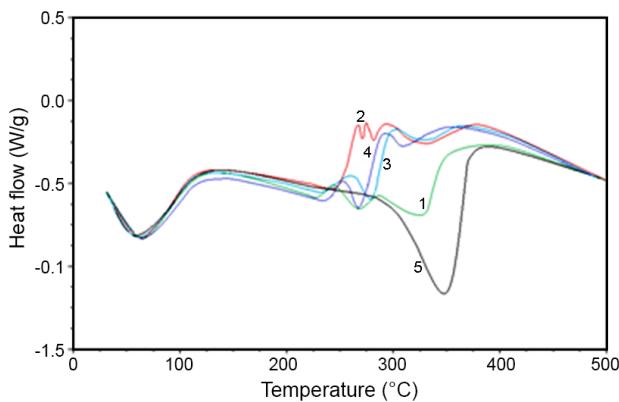


Fig. 8. DSC analysis of: (1) untreated jute fabric sample and the samples treated with different polyurea (2) 1P/4U, (3) 1S/4U, (4) 1S/1P/10U, and (5) 2S/3P/8U.

However, for the samples treated with 1P/4U compound and also 1S/1P/10U, the endothermic decomposition process occurred in two steps which depend on the new chemical structure of the samples. The similarity of thermal pyrolysis represents that no significant difference can be announced in chemical structure of these two treated samples.

In synthesis of these compounds one mole of phosphorous acid was used. In principle the amount of phosphorus element has an essential role on thermal behavior of treated samples. On the other hand, by increasing the level of phosphors and also sulfur groups

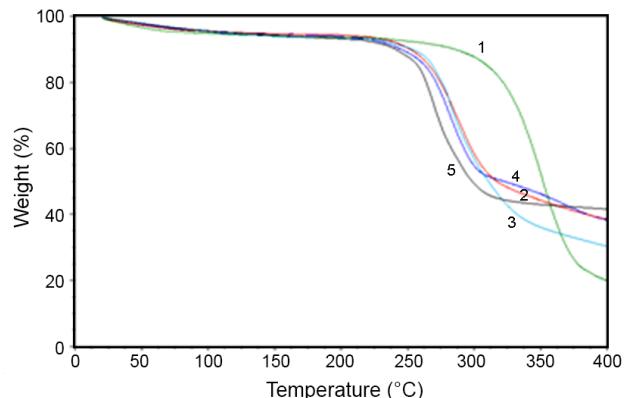


Fig. 9. TGA results of: (1) untreated jute fabric sample and samples treated with (2) 1P/4U, (3) 1S/4U, (4) 1S/1P/10U, and (5) 2S/3P/8U.

H. LOI Results

The limited oxygen index values of treated samples were measured. The comparison of flame retardant performance and their predicted sulfur, phosphorus, and also nitrogen element on each sample relevant to the type of applied polyurea has been presented in Table VI.

The treatment of jute fabric with urea new products changed its color, which is not undesirable. The effect of these materials on FR properties was also studied, and no burning, no glow, and small char were observed. The durability of this treatment was confirmed in hard water with washing agent. The present of urea, phosphorous, and

TABLE V
PYROLYSIS STEPS OF FABRIC SAMPLES TREATED WITH VARIOUS TYPES OF OLIGOMERS

Oligomers	Step 1 (°C)		Step 2 (°C)		Step 3 (°C)		Char (%)
	Start	Centred	Start	Centred	Start	Centred	
1P/4U	40	68	223	290	310	347	37.5
1S/1P/10U	42	79	250	280	322	325	37.8
1S/4U	41	77	240	280	330	316	30
2S/3P/8U	42	78	260	283-288*	310	347	42.6

*Exothermic reaction occurred in two picks

TABLE VI
FLAME RETARDANT BEHAVIOR OF TREATED SAMPLES ACCORDING TO THE ELEMENTAL PREDICTION ON EACH ONE

Type of samples	The predicted element			Glow formation	LOI
	N	P	S		
Non- treated sample	-	-	-	Yes	0.21
Treated sample with 1P/4U	27.76	7.68	-	No	0.39
Treated sample with 1S/4U	27.76	-	6.24	Yes	0.24
Treated sample with 1S/1P/10U	28.72	3.18	3.12	No	0.27
Treated sample with 2S/3P/8U	19.44	8.08	5.52	No	0.41

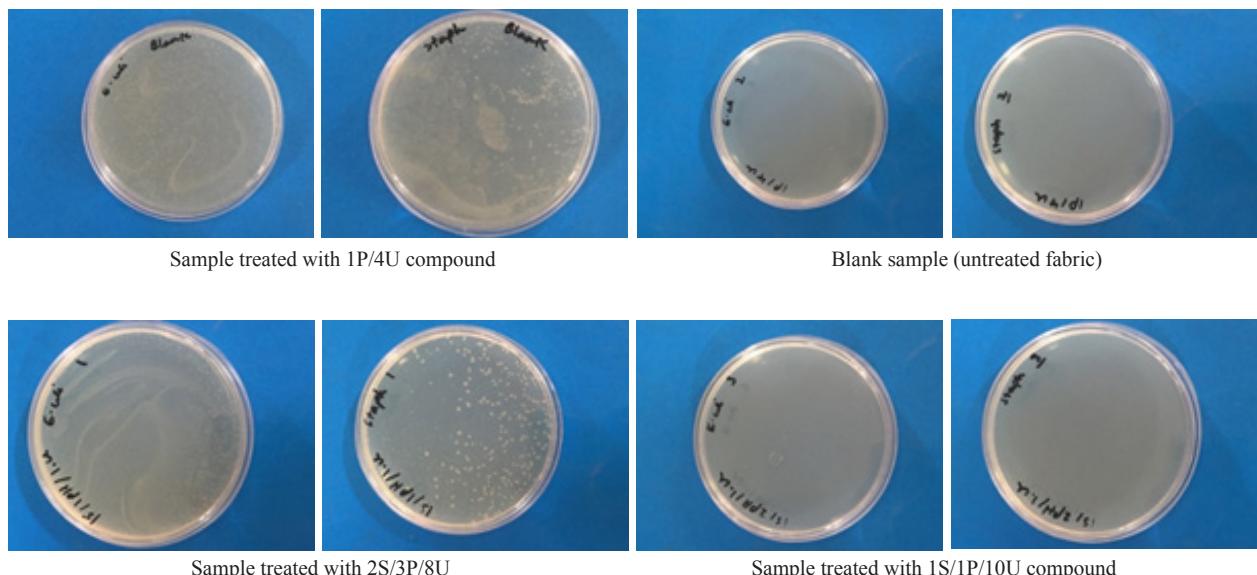


Fig. 10. Antibacterial activity of the blank fabric and some of the treated samples against *E. coli* and *S. aureus* bacteria.

also sulfamic acid changed the procedure of fabric burning to the condensate phase mechanism and more char was expected.

The correlation between the limited oxygen index and the amount of essential elements on the surface of fabric samples has been indicated. The predicted nitrogen, phosphorus, and sulfur groups are calculated according to the urea products solution on each sample after finishing treatment. The 1S/4U compound provides self-extinguishing on samples however the glow formation during burning on the surface of fabric decomposes the surface of samples and makes a hole on it. The treated compound containing phosphorus element can protect the fabric from glow formation which is very important during burning.

I. Antibacterial Activity

The antibacterial test was performed on all samples treated with various types of synthesized oligomers. In a

standardized test, if the reduction of the microorganism is greater than 80%, the antibacterial activity of sample has been confirmed. The results for the reduction of two common *Staphylococcus aureus* and *Escherichia coli* bacteria are indicated in Fig. 10 and Table VII. In two treated samples, a significant improvement, more than 99% reduction, can be clearly seen.

The antibacterial activity of treated fabric has been evaluated with the amount of phosphorus element on them. In the fabric sample treated with compound containing 1 mole sulfamic acid, 1 mole phosphorous acid, and 10 moles of urea with the lowest level of phosphorus no antibacterial effect has been achieved.

IV. CONCLUSION

Diverse products can be synthesized using various molar ratios of inorganic acids and urea. As it has been expected, their effect as a flame retardant on jute fabric is also different. The cost of initial materials plays an important

TABLE VII
ANTIBACTERIAL ACTIVITY OF SOME SAMPLES

Sample	<i>S. aureus</i>		<i>E. coli</i>	
	Surviving cells (CFU/mL)	Reduction (%)	Surviving cells (CFU/mL)	Reduction (%)
Non-treated	1.5×10^3	NC*	1.5×10^3	NC
Treated fabric with 1P/4U	1.5×10^3	99.9	1.5×10^3	99.9
Treated fabric with 1S/1P/10U	1.5×10^3	NC	1.5×10^3	NC
Treated fabric with 2S/3P/8U	1.5×10^3	99.9	1.5×10^3	99.9

role to prepare the products. The cost of urea is very low in comparison with that of other materials, therefore to design the new compound, the reaction between 1 mole of sulfamic acid and 1 mole of phosphorous acid with 4 and 10 moles of urea was investigated. In fact, by selecting the appropriate amount and the type of initial materials in the chemical synthesis, it is possible to design new specific FR materials according to the substrate to achieve the highest level of flame retardancy and antibacterial properties.

In this research, the durable FR performance on jute fabric is confirmed with no halogenated FR. The antibacterial effect produced on the fabric is also significant. This treatment can reduce the hydroxyl groups of the jute fabric with some new cross-linkings. Therefore, the compatibility of this fabric with other hydrophobic materials in composite would be improved.

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